Historic Inshore Distributions of Hatchery and Wild Juvenile Salmon and Young-of-the-Year Herring in the Strait of Georgia, British Columbia, With Implications for Explaining Variability in the Returns of Coho and Chinook Salmon

R.W. Tanasichuk, A.W. Argue, and R.W. Armstrong

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

2008

Canadian Technical Report of Fisheries and Aquatic Sciences 2792

Fisheries and Oceans | Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sceiences aquatiques et halieutiques*, et ils sont classés dans l'in !ex annual des publication scientifiques et techniques du Ministère.

Les numéros 1à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2792

2008

HISTORIC INSHORE DISTRIBUTIONS OF HATCHERY AND WILD JUVENILE SALMON AND YOUNG-OF-THE-YEAR HERRING IN THE STRAIT OF GEORGIA, BRITISH COLUMBIA, WITH IMPLICATIONS FOR EXPLAINING VARIABILITY IN THE RETURNS OF COHO AND CHINOOK SALMON

By

R. W. Tanasichuk[1], A. W. Argue[2], and R. W. Armstrong[3]

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, B. C. V9T 6N7

[1]- email: Ronald.Tanasichuk@dfo-mpo.gc.ca
[2] - Argus Bio-Resources Ltd. 4050 Lockehaven Drive, Victoria, B.C. Canada. V8N 4J5.
[3] - Armstrong Bio/Tech Services. 8042 Armstrong Road, Langley, B. C. Canada. V1M 3T6.

Her Majesty the Queen in Right of Canada 2008
Cat. No. Fs 97-6/2792E ISSN 0706-6457

Correct citation for this publication:

Tanasichuk, R. W., Argue, A. W., and Armstrong, R. W. 2008. Historic inshore distributions of hatchery and wild juvenile salmon and young-of-year herring in the Strait of Georgia, British Columbia, with implications for explaining variability in the returns of coho and chinook salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2792: vi + 36p.

TABLE OF CONTENTS

ABSTRACT v
INTRODUCTION 1
METHODS 2
Data 2
Statistical analysis 4
RESULTS 5
Set distributions 5
Fish distributions 5
Coded-wire tag data 6
Species interactions 6
Evaluation of effects of stock, young-of-the-year herring abundance and harbour seal abundance on marine survival rate or total return 6
DISCUSSION 6
REFERENCES 10

LIST OF TABLES

Table 1. Number of purse-seine sets 13
Table 2. Frequency of no significant effects of area on CPUE, within region 14
Table 3. Median (first row) and range (second row) of CPUE by region and sampling period, 1973. Minimum CPUE in all instances is 0. 15
Table 4. Median proportion of hatchery chinook and coho caught, 1973. Values in parentheses are total number of fish caught. b – no hatchery fish caught 16
Table 5. Coded-wire tag returns, 1973. FR – Fraser River estuary; BH – Burrard Inlet/Howe Sound; UW – Upper West Strait; LW – Lower West Strait; ES – Eastern Strait; UG – Upper Gulf Islands; LG – Lower Gulf Islands. Days – minimum to maximum days at large 17
Table 6. Correlation coefficients for CPUE, 1972-1974. * - $p<0.05$; ** - $p<0.01$. 18
Table 7. Statistics for regression analyses. β' – standardised regression coefficients. p_{adj} -Bonferroni adjusted probability. a- CWT marine survival. b – total return 19
Table 8. Wild spawning escapement and hatchery juvenile production of chinook and coho, Strait of Georgia for the 1973 outmigration year. Spawning escapements are for brood year +1 for chinook because Argue and Marshall (1976) reported that stream-type chinook, fish which rear in freshwater for at least one year, made up less than 6% of the Strait of Georgia troll catch. So, most chinook would be ocean-type which are fish which rear in freshwater for several months only. Spawning escapements for coho are for brood year + 2 because coho rear in freshwater for one year. Wild escapement data are from Anderson (1977) 20

LIST OF FIGURES

Figure 1. Study area. Numbers identify areas. The Fraser River region consists of Areas 0 (Fraser River estuary) and 1 (Burrard Inlet/Howe Sound). The Central Strait region includes Areas 2 (Upper West Strait), 3 (Eastern Strait), and 4 (Lower West Strait). The Gulf Islands region consists of Areas 5 (Upper Gulf Islands) and 6 (Lower Gulf Islands). Lines seaward of the coast are the 50 and 100 m depth contours respectively. The 50 and 100 m contours are an average of 0.9 and 2.7 km respectively away from shore. The top of the figure is North.....21
Figure 2. Length-frequency histogram for chinook salmon seined over 1972-74. Values are counts. Dotted line is at 240 mm.....22
Figure 3. Length-frequency histogram for coho salmon. Dotted line is at 370 mm.....22
Figure 4. Length-frequency histogram for chum salmon. Dotted line is at 300 mm.....23
Figure 5. Length-frequency histogram for herring. Dotted line is at 90 mm.....23
Figure 6. Cumulative density plot for bottom depth at purse seine set locations.....24
Figure 7. Observed (closed circle) and predicted (open circle) marine survival rate for Quinsam Hatchery coho.....24
Figure 8. Observed and predicted marine survival rate for Black Creek wild coho.....25
Figure 9. Observed and predicted marine survival rate for Big Qualicum Hatchery coho.....25
Figure 10. Observed and predicted marine survival rate for Salmon River wild coho.....26
Figure 11. Observed and predicted marine survival rate for Chilliwack River Hatchery coho.....26
Figure 12. Observed and predicted marine survival rate for Inch Creek Hatchery coho.....27
Figure 13. Observed and predicted total return for North Thompson River coho.....27
Figure 14. Observed and predicted total return for South Thompson River coho.....28
Figure 15. Observed and predicted total return for Lower Thompson River coho.....28
Figure 16. Observed and predicted marine survival rate for Cowichan River fall chinook.....29

LIST OF APPENDIX TABLES

Appendix Table 1. Population-specific coho smolt abundance, total return, parental abundance, and total coho and chinook smolt releases by smolt and return year.....31
Appendix Table 2. Brood year-specific wild and hatchery smolt production, parental abundance and total return for Cowichan River fall chinook salmon.....35
Appendix Table 3. Smolt year-specific young-of-the-year Pacific herring (YOY) CPUE (no. fish • m^{-3}) and harbour seal abundances in the Strait of Georgia. 36

ABSTRACT

Tanasichuk, R. W., Argue, A. W., and Armstrong, R. W. 2008. Historic inshore distributions of hatchery and wild juvenile salmon and young-of-year herring in the Strait of Georgia, British Columbia, with implications for explaining variability in the returns of coho and chinook salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2792: vi + 36p.

We used species composition data from 326 inshore (<3 km from shore) purse-seine sets made between June and October, 1972-74 to learn about the distributions of juvenile wild and hatchery salmon (*Oncorhynchus* sp.), and young-of-the-year herring (*Clupea pallasi*), in the Strait of Georgia. Time and location affected the distributions of all species-origin (hatchery versus wild) groups differently. The frequency of significant correlations of CPUE (number of fish per set) among species-origin groups increased with time primarily because chinook and coho CPUE became correlated with herring CPUE later in the year. Subsequent preliminary analyses evaluated the effects of smolt and/or parental abundance, young-of-the-year herring abundance, and in addition, harbour seal (*Phoca vitulina*) abundance, on readily available CWT (coded-wire tag) marine survival rate or total return data for some monitored salmon populations that use the Strait of Georgia. These included nine coho (*O. kisutch*) salmon populations and Cowichan River fall chinook (*O. tshawytscha*) salmon. We calculated statistically significant regressions for seven of the 10 populations; results for the other populations were suggestive. There were significant effects of hatchery smolt release or parental abundance on CWT marine survival or total return for two of the populations, significant effects of herring in three instances, and significant effects of seal abundance for six of the seven populations. The magnitude of the seal and herring effects varied among populations. Seal abundance effects were exerted during the first marine year. These results suggest that future studies should consider the various mechanisms by which smolt and/or parental abundance can affect productivity, and should also consider that biotic factors affecting returns can be population-specific.

RÉSUMÉ

Tanasichuk, R.W., Argue, A.W., and Armstrong, R.W. 2008. Historic inshore distributions of hatchery and wild juvenile salmon and young-of-year herring in the Strait of Georgia, British Columbia, with implications for explaining variability in the returns of coho and chinook salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2792:vi + 36 p.

Dans le but d'en savoir davantage sur la répartition des saumons (*Oncorhynchus* sp.) juvéniles (sauvages et d'écloserie) et des jeunes harengs (*Clupea pallasi*) de l'année dans le détroit de Georgia, nous avons utilisé des données sur la composition des espèces tirées de 326 traits côtiers (à moins de 3 km de la côte) à la senne coulissante, effectués entre les mois de juin et d'octobre, de 1972 à 1974. Le temps et l'emplacement avaient une incidence différente sur la répartition de tous les groupes, espèces et origines confondues (sauvages et d'écloserie). La fréquence des corrélations significatives des CPUE (nombre de poissons par trait) augmentait avec le temps parmi les groupes de différentes espèces et origines, principalement parce qu'une corrélation a été établie entre les CPUE de saumons quinnats et cohos et les CPUE de harengs plus tard dans l'année. Des analyses préliminaires subséquentes ont évalué les effets de l'abondance de smolts et/ou de leurs parents, de l'abondance des jeunes harengs de l'année et de l'abondance du phoque commun (*Phoca vitulina*) sur les données de taux de survie en mer et de remonte totale (données facilement accessibles par micromarques magnétisées codées) de certaines populations de saumons surveillées qui empruntent le détroit de Georgia. Parmi ces dernières, on compte neuf populations de saumons cohos (*O. kisutch*) et de saumons quinnats (*O. tshawytscha*) de la rivière Cowichan. Nos calculs ont donné des régressions statistiquement significatives chez sept des dix populations étudiées, et les populations restantes ont montré des résultats intéressants. On a observé des effets significatifs du lâcher de smolts d'écloserie et de l'abondance de leurs parents sur le taux de survie en mer ou la remonte totale de deux des populations étudiées, données obtenues au moyen de micromarques magnétisées codées. On a aussi constaté des effets significatifs du hareng sur trois populations et des effets significatifs de l'abondance du phoque commun sur six des sept populations étudiées. L'ampleur des effets du phoque et du hareng variait d'une population à l'autre. Les effets de l'abondance du phoque se faisaient sentir la première année en mer. Ces résultats laissent entrevoir l'importance de considérer, dans le cadre d'études futures, les divers mécanismes par lesquels l'abondance de smolts et/ou de leurs parents peut affecter la productivité, et que les facteurs biotiques ayant une incidence sur la remonte sont potentiellement propres à chaque population.

INTRODUCTION

The Strait of Georgia is the early marine rearing area for the majority of southern British Columbian salmon populations, and juvenile salmon distribution there has been examined by a number of investigators. Earlier work in the Strait included inshore sampling sites, defined as between the littoral zone and about 3 km from shore. Studies began in 1965 (Godfrey 1968) with a preliminary survey designed to evaluate using seines for sampling, and to provide preliminary information on fish distribution and size. Barraclough and Phillips (1978) described the results from two-boat surface trawl catches in the Fraser River estuary and the southern Strait from April through October 1966-69. Beamish *et al.* (1976) reported catches from a purse seine survey of the surface waters of the Strait during the summer of 1974. Healey (1978) presented the results of purse seine surveys conducted in 1975 and 1976. Groot *et al.* (1985) reported the results of extensive purse seine surveys done in 1982-84. All recent work, for example Beamish *et al.* (2000), focuses on sampling further offshore.

The inshore region has received cursory attention by the majority of studies which examined juvenile salmon distribution in the ocean, yet it is the only habitat where high marine mortality has been demonstrated. Studies that included inshore sampling (Godfrey 1968, Beamish *et al.* 1976, Barraclough and Phillips 1978, Dawley *et al.* 1981, Straty 1981, Brodeur *et al.* 2004) reported concentrations of juvenile salmon there. There has been only one study (Parker 1968) which estimated mortality rates during the inshore and subsequent oceanic periods. Parker concluded that the mortality rate for pink salmon (*Oncorhynchus gorbuscha*) from the Bella Coola River was much greater during the first 40 days of marine life when the fish were inshore.

The Canadian Department of Fisheries and Oceans (DFO) has been releasing hatchery chinook (*O. tshawytscha*) and coho (*O. kisutch*) into the Strait since 1968. There has been long-term and wide-spread concern about the interactions between hatchery and wild salmon because of the potential impact of cultured fish on wild stocks, but few studies have been done in marine waters. Zaporozhets and Zaporozhets (2004) reported that releases of chum (*O. keta*) from Japanese hatcheries have affected growth, fecundity and health of Russian wild chum. Boldt and Haldorson (2004) concluded that neither hatchery or wild pink salmon in Prince William Sound had a competitive advantage over one another because energy content (calories$\cdot g^{-1}$) was affected by location, and not origin of fish. King and Beamish (2000) suggested that hatchery coho in the Strait of Georgia may affect survival of wild coho because their diets overlapped. However, data presented by Sweeting *et al.* (2003) suggests that wild juvenile production accounted for just 3% of the total at the time of King and Beamish's study. Since only 50 to 60% of the hatchery coho were marked then, it is likely that King and Beamish's results are for unmarked hatchery coho versus marked hatchery coho rather than hatchery versus wild fish.

This study used data from 326 purse-seine sets made in 1972-74 to learn about the inshore distributions of hatchery and wild juvenile chinook, coho, and chum salmon in their first ocean year, and young-of-the-year Pacific herring (*Clupea pallasi*), in the Strait of Georgia. The impetus for this work was Parker (1968)'s result. The overall objective was to provide information for investigating the biological basis of juvenile chinook and coho marine survival variation in the Strait. A comprehensive evaluation of factors affecting marine survival should

include the inshore rearing area, and, in addition, should at some time consider species and/or origin (hatchery, wild) interactions. Consequently, there were two initial objectives of this study. They were to test the effects of location and time on the inshore distribution of hatchery and wild juvenile salmon and herring, and to test for correlations in CPUE (catch per unit effort, number of fish caught per set) to identify potential inter- and intra- (hatchery/wild)-species interactions. The significant correlations between herring and coho and herring and chinook CPUE's gave rise to an *ad hoc* objective. It was to conduct a preliminary test of the effects of young-of-the-year herring abundance and hatchery releases on marine survival rate or total return of selected Strait of Georgia coho and chinook populations. Finally, we took advantage of a time series of harbour seal (*Phoca vitulina*) abundance (see Olesiuk 1999) to evaluate the effect of seal abundance on coho and chinook returns.

METHODS

Data

Fish were purse-seined in seven areas within three regions (Fraser River, Central Strait, Gulf Islands; Fig. 1) of the Strait of Georgia. The areas and regions were defined by proximity to the Fraser River, relative exposure of the coastline, the prevalence of islands and tidal passages, and on which shore (western, eastern) of the Strait they occurred. Sampling periods ranged between May 30 and June 27, July 11 and August 22, and September 5 and October 18, 1972-74. They are referred to as the June, July-August, and September-October cruises respectively. The seine was a 184 m x 15 m net with 46 m of 25 mm mesh, 92 m of 13 mm mesh and a 46 m bunt of 6 mm mesh. Most sets were made based on observations of juvenile salmon jumping at the surface or showing as traces on a Furuno Model 602 dry paper-sounder. About 25 percent of the sets were made blind, that is, where there was no indication of the presence of fish.

The entire catch was sampled when possible. Fish were identified to species and counted. Subsamples were taken from the sets when catches were large. In these instances, dipnets were used to empty the seine net. The number of fish caught per species (N_j) was estimated as:

$$N_j = t \bullet k^{-1} \bullet d_j$$

where N is the number of fish, j is species, t is the number of dipnet samples required to remove the catch, k is total number of dipnet subsamples retained, and d is number of fish per species in the dipnet subsamples retained. Length-frequency histograms (Figs. 2-5) were used to identify juvenile salmon in their first ocean year and to define young-of-the-year Pacific herring. Juvenile chinook, coho and chum were defined as fish shorter than 240, 370, and 300 mm fork length respectively. Herring shorter than 90 mm standard length were considered to be young-of-the-year fish.

All coded-wire tagged hatchery fish, identified by a clipped adipose fin, were preserved in

5% formalin for laboratory analysis. Coded-wire tags were removed and decoded at the DFO laboratory for the Mark Recovery Programme. We used the tag code to learn the location and date of release, the number of fish tagged in a release, and the total number of fish released (R. Cook, pers. comm., DFO). Because many of the hatchery fish were unmarked, expansion factors ($E_{h,j,r}$) were calculated so that the number of hatchery fish caught in a set could be estimated. The calculation was:

$$E_{h,j,r} = N_{h,j,r} \bullet N^{-1}_{h,j,m,r}$$

where h is hatchery, r is release and m is marked (coded-wire tagged). The number of hatchery fish per species captured in a set was estimated as:

$$N_{h,j,s} = E_{h,j,r} \bullet N_{h,j,m,r,s}$$

where s is set. The number of wild fish in the set was estimated as the difference of total number of fish per species caught in the set and the expanded number of hatchery fish.

We used published data on salmon smolt abundance, parental abundance and total return for our subsequent analysis of the effects of stock, young-of-the year herring abundance, and harbour seal abundance on survival. Information on coho populations was reported in Simpson *et al.* (2004) (Appendix Table 1). Cowichan River chinook hatchery and wild smolt production, spawner abundance and total return data were presented in Tompkins *et al.* (2005) (Appendix Table 2). Total hatchery releases by year and species were calculated using release data accessed through "http://www-heb.pac.dfo-mpo.gc.ca/facilities/hat-fw-sc_e.htm". Marine survival rate (SR) was estimated as:

$$SR_{x,i} = A_{x,i+1} \bullet S^{-1}_{x,i}$$

where x is hatchery or wild stock, i is smolt year, A is return, and S is number of smolts. We could not partition freshwater and marine survival for Thompson River coho because there are no estimates of smolt abundance and consequently used total return as the response variable.

Young-of-the year herring abundance estimates were calculated from data collected during annual juvenile herring surveys in the Strait of Georgia (e.g. Thompson and Hrabok 2007). Purse seine sets have been made at specific locations along a number of transects and at various times of the year. There are 10 transect lines that have been fished consistently in September and October since 1990, except for 1995. We estimated annual median CPUE of young-of-the-year herring using the catch data from the stations along the 10 transect lines sampled in September-October (Appendix Table 3). The seine net used for the 1990 survey was 400 m long and 27 m deep, and the seine used for all subsequent years was 227 m long and 27 m deep. We estimated CPUE as the number of fish per cubic meter fished after assuming that the nets took a cylindrical form when they were set.

Harbour seal abundance estimates came from harbour seal surveys (Olesiuk 1999). It

appears that seal abundance in the Strait has stabilised (P. Olesiuk, Pacific Biological Station, Nanaimo, B. C., *pers. comm.*) so we assumed that abundance has not changed since the 1998 census (Appendix Table 3).

Statistical analysis

We analysed the data using the statistical package JMP (SAS Institute Inc., Cary, NC). Analyses of residuals for analyses-of-variance (ANOVA) using untransformed or natural log-transformed (ln (CPUE+1)) catch data, and untransformed or arc sin transformed proportion data, showed that the residuals were not normally distributed. So, the nonparametric Kruskal-Wallis test was used to evaluate the influence of time and location on catch. We used the extension of the Kruskal-Wallis test that Conover (1980) recommended to do pairwise comparisons of rank means among groups. The effects of time and location were tested using the 1973 data only because sampling was fragmentary for 1972 and 1974. Data from the Eastern Strait area were excluded because only three sets were made there.

Spearman's rho statistic was used to test for correlations in CPUE among species-origin groups because neither CPUE or ln (CPUE+1) were normally distributed. Wilkinson *et al.* (1996) recommend using Bonferroni-adjusted probabilities to reduce the possibility of committing a Type I error when evaluating all possible pairwise tests, such as the tests for statistically significant correlations in CPUE. The adjusted probabilities are estimated as:

$$p_{adj} = p \bullet c^{-1}$$

where p is the critical value at α=0.05 or 0.01 at the appropriate degrees of freedom and c is the number of comparisons.

Stepwise multiple regression analysis was used to evaluate the effects of stock (smolt abundance, parental abundance), young-of-the-year herring abundance, and harbour seal abundance on CWT marine survival or total return variability. The sum of coho and chinook releases for a given hatchery was also tested because chinook and coho smolts were released at the same time (D. Ewart, DFO, *pers. comm.*). Testing included evaluating the effect of density on marine survival (see Peterman 1978, 1982). All possible one- and two-factor models were tested. Natural log-transformed variates were used when necessary so that the studentised residuals would be normally distributed. Stepwise multiple regression testing included the environmentally-dependent Ricker stock-recruit relationship (Hilborn and Walters 1992) where the dependent variable would be ln (recruits•spawner^{-1}). We followed the recommendation to use deviations of non-stock effects. We lagged seal abundance back one year so that we could test for effects exerted during the coho's second ocean year. We concluded that any effect of seal abundance would have been exerted during the first marine year if parameter estimates did not change significantly when lagged abundance was used. The final step in the multiple regression analysis was to test for significant improvement in Adjusted R^2 with the addition of a third, and if necessary, additional independent variables. For both types of regression testing, we used the F-test that Sokal and Rohlf (1995) recommended to evaluate the significance of the increase in

R^2 associated with the inclusion of an additional independent variable. The Durbin-Watson statistic was used to test for significant auto-correlation in the studentised residuals because all dependent and independent variables were from time series. We calculated standardised regression coefficients (β') so that we could estimate the proportion of the explained variation accounted for by an independent variable. The proportion of explained variation accounted for by a given variable was calculated as the standardised regression coefficient for that variable divided by the sum of the standardised regression coefficients for all variables. The Bonferroni-adjusted probabilities were used to evaluate the statistical significance of the regressions.

Results of all tests were accepted as being significant if $p<0.05$.

RESULTS

Set distributions

Purse-seining occurred in all regions and during all cruises during 1973, but was less comprehensive in 1972 and 1974 (Table 1). The median water depth of set locations was 16 m, and all sets were made in waters less than 135 m deep (Fig. 6). The median distance from shore for all sets was 500 m and the maximum distance was 2.7 km.

Fish distributions

Data from blind and informed (indications of fish presence) sets, and also among areas within regions, were pooled because there was no significant effect of set type or area on CPUE. The effect of set type was tested using a subset of 53 sets from the entire dataset, where there was minimum of five sets of each type for a species-origin-year-cruise-area category. There was one instance (young-of-the-year herring in the 1972, Burrard Inlet/Howe Sound, September-October) of the 18 tested where set type affected CPUE significantly. A G-test of independence was calculated using exact probabilities as Sokal and Rohlf (1995) recommend when $n<25$. The single instance of significant difference in CPUE between set type was not significantly different from no differences. Results of Kruskal-Wallis tests showed instances where there were differences in CPUE due to area within a species-origin-region-cruise stratification. Results of G-tests of independence, calculated using exact probabilities, showed that the frequencies of areal differences were not significantly different from homogeneity (Table 2).

There were significant effects of region and sampling period on the CPUE of all species-origin groups (Table 3). The CPUE for hatchery chinook was higher in the Central Strait in July-August. Wild chinook CPUE was higher in the Fraser River region in June and July-August, and in the Gulf Islands region in July-August and September-October. CPUE for hatchery coho was higher in the Fraser River region in June and July-August, and in the Central Strait region during September-October. CPUE for wild coho was higher during July-August in the Gulf Islands region, and in the Central region in September-October. Chum CPUE was higher in the Central Strait and Gulf Islands regions in June and July-August. Young-of-the-year herring CPUE was higher in the Fraser River and Gulf Islands regions over all cruises.

The proportions of hatchery chinook and coho were significantly different over regions and sampling periods (Table 4). The proportion of hatchery chinook in the Central Strait in July-August was greater than all other region-sampling period combinations. The proportion of hatchery coho was greater in the Central Strait region over all sampling periods, and in the Fraser River region in June.

Coded-wire tag data

There were differences in dispersal patterns of coded-wire tagged juveniles that appeared to be associated with species and hatchery location (Table 5). Recaptures of chinook suggested that their movement is limited whether fish are from hatcheries on the southeastern (Burrard Inlet/Howe Sound) or northwestern (Upper West Strait) coast of the Strait. Coho from the Burrard Inlet/Howe Sound area dispersed to the Gulf Island region and subsequently to the Central Strait region. Coho from the Upper West Strait showed the same limited dispersal that chinook juveniles did.

Species interactions

The frequency of significant correlations of CPUE among species-origin groups increased from summer to fall (Table 6). Hatchery and wild coho CPUE were positively correlated in July–August, and more strongly correlated in September–October. In September-October, herring CPUE was negatively correlated with coho CPUE and positively correlated with chinook CPUE.

Evaluation of effects of stock, hatchery releases, young-of-the-year herring abundance and harbour seal abundance on marine survival rate or total return

We calculated statistically significant regressions that explained marine survival rate or total return variability for seven of the nine coho stocks (Table 7). Different factors explained return variability among the populations. There were effects of stock or hatchery releases in two instances, effects of herring in three instances and effects of seals in six instances. Seal abundance accounted for between 0.55 and 0.81 of the explained variability, and all effects of seals were exerted during the first marine year. Figures 7 through 16 show the comparisons of predicted to observed marine survival rate or total return. Regressions for Black Creek and lower Thompson River coho, and Cowichan River fall chinook are suggestive (see Figs. 8, 15 and 16).

DISCUSSION

There are statistically significant effects of location and time on the inshore distribution of wild and hatchery juvenile chinook and coho, juvenile chum, and young-of-the-year herring in the Strait of Georgia. We could not compare our results with most other studies in the Strait of Georgia because they did not distinguish between inshore and other sampling areas. Beamish *et*

al. (1976) evaluated the statistical significance of the differences in CPUE between inshore and other areas. They reported that coho catches were significantly higher within 3 km of shore.

The distribution of species-origin groups we report reflected local centers of production and dispersal for chinook, coho, chum and herring. Estimates of the spawning escapements and hatchery releases relevant to the 1973 out-migration year are presented in Table 8. Hatchery chinook concentrated near hatchery release locations. It appears that, for wild chinook, Fraser River production dominated. The significantly greater CPUE in the Fraser River region during early to mid-summer reflected that, yet wild chinook concentrated in the Gulf Islands region later in the season. These may be mostly Cowichan River chinook, as suggested by results from Argue *et al.* (1986), but may have also included substantial numbers of juveniles of Fraser River origin that dispersed rapidly across the Strait in the Fraser plume to the southern Gulf Islands (Barraclough and Phillips 1978). The higher CPUE's of hatchery coho in the Central Strait seems to have reflected the hatchery-specific movements. Fish from the Fraser River region (Burrard Inlet/Howe Sound area) appear to have moved across the Strait of Georgia to the Gulf Islands region and then to areas occupied by hatchery coho from the Central Strait region which, in turn, appeared to be sedentary. Wild coho distributions could also have been a consequence of fish moving across the Strait from the Fraser River region, after which they joined juvenile coho produced in the Gulf Islands region. It appears that wild coho moved subsequently to the Central Strait region as indicated by statistically higher the CPUE there in September-October. The peak CPUE's for chum in June and July-August likely reflected their movement into the Strait and the subsequent, and relatively rapid, out-migration (Healey 1978). The concentration of herring reflected historic spawn deposition data (http://www.pac.dfo-mpo.gc.ca/sci/herring/herspawn/spaVidS.htm). Spawning was concentrated in the Lower West Strait area and Gulf Islands region in 1973. However, the higher CPUE in the Fraser River region suggested a movement of herring into the open Strait.

We suggest that there are interesting subtleties of juvenile salmon movement described in our data. The most notable is the apparent differences in dispersal patterns among hatchery juveniles. Results in Table 5 showed that hatchery chinook, and hatchery coho from the western shore of the Strait of Georgia, were sedentary while hatchery coho from the eastern shore moved across the Strait. The limited movement of hatchery chinook explains our results which showed that the proportion of hatchery chinook was significantly greater in the Central Strait region in July-August. These high concentrations reflected relatively large hatchery releases and limited production from wild stocks in the region. There is additional evidence that hatchery coho from the eastern shore of the Strait move to the western shore whereas fish from hatcheries on the western shore remain on that side of the Strait of Georgia. Beamish *et al.* (1976) recaptured three hatchery juveniles on the western shore of the Strait. One was from the Big Qualicum River hatchery, located on the western shore of the Strait, and the other two fish were from the Capliano River hatchery, located on the eastern shore of the Strait. Argue *et al.* (1986) found that CWT'ed wild chinook juveniles from the Cowichan River (in our Upper Gulf Islands area) dispersed significantly less from their release sites than did CWT'ed wild coho juveniles.

It is conceivable that interactions with young-of-the-year herring affect the productivity

of some Strait of Georgia coho populations. As mentioned above, Parker (1968) is the only study which partitioned marine survival into inshore and oceanic phases, and he found that most of the mortality occurred early in marine life, when fish were inshore. Our results suggest that the return of three of the seven coho populations for which we could describe statistically significant effects was adversely affected by nearshore interactions with young-of-the-year herring. CPUE data from Table 3 shows that herring abundances were about 100 times those of coho juveniles, so it is possible that young-of-the-year herring could influence inshore habitat utilisation by coho. The negative correlations between herring and coho CPUE for September-October could be a consequence of coho avoiding herring. Preliminary results (Argue, *unpubl. res.*) show that euphausiids < 15 mm long are key prey items for coho and herring in inshore waters, so herring could be displacing coho from preferred inshore feeding areas. Beamish *et al.* (2001) suggested that juvenile herring could be prey for coho when oceanic conditions are favourable, and competitors when conditions are unfavourable. Our results suggest that an adverse effect of young-of-the-year herring abundance persists. Additional testing and field studies would be necessary to confirm an effect of herring abundance on coho distribution and consequently survival.

It is also conceivable that harbour seal predation could be affecting Strait of Georgia salmon production. Our results demonstrate that an interaction with seals affects returns of six of the seven coho stocks for which statistically significant regressions were calculated, and suggests an effect on Black Creek coho, lower Thompson River coho and Cowichan River fall chinook. Results presented in Olesiuk *et al.* (1990) suggest that seals and salmon would co-occur in estuaries at least. Seal abundance in small estuaries was stable over January to June, increased rapidly until September, and then decreased to a minimum in December. Abundance in the Fraser River estuary increased continuously from March until September, and then declined to a minimum in December. Olesiuk *et al.* estimated that harbour seals consumed about 400 tonnes of salmon, mainly adults. Unfortunately there are weaknesses in the analyses which suggest that salmon consumption by seals is underestimated. These weaknesses are largely a consequence of the difficulties associated with describing seal diets that Olesiuk *et al.* and Cottrell (1995) discuss at length. First, diet composition was described on the basis of frequency of occurrence and ignored number and size of prey, which can reflect selectivity, as well as prey volume, which is a more direct measure of prey consumption. Second, the descriptions of diet assume that equal masses of all prey are consumed, which is highly unlikely. If this were true, then a much higher number of juvenile salmon would be eaten than adults because they are so much smaller. Third, smaller fish have smaller boney structures which, if detected less efficiently, would result in smaller prey being under represented in scat analysis. Cottrell (1995) cited studies which reported that boney structures from small prey tend to be totally digested. Finally, scat sampling focussed on seals in estuaries so scat analysis outside of estuaries is under represented. There have been two other studies which addressed harbour seal predation on salmon. Cottrell (1995) studied the diet and activity of harbour seals in Cowichan Bay and adjacent areas. He reported that the occurrence of salmon in the diet in May coincided with the release of salmon smolts into the Cowichan River estuary. Estimated prey size (mean=10 g) was within the size range of smolts released from the hatchery. In addition, Cottrell (1995) found that the increase in salmon spawner abundance in the fall was reflected in increases in seal abundance

and the occurrence of salmon in the diet. Bigg *et al.* (1990) described the movements, feeding behaviour, and predation rate of harbour seals and sea lions (*Zalophus californianus*, *Eumetopias jubatus*) on pink, chum, coho and chinook salmon in Comox Harbour and Cowichan Bay during 1989-90. They estimated that seals and sea lions consumed less than 10% of the adult pink, chum and coho returns. This suggests that the seals may affect coho returns by feeding on juveniles. We suggest that, as for the case of the interaction with herring, additional studies would have to be undertaken to evaluate rigorously the effect of harbour seal predation on Strait of Georgia salmon productivity.

We found six significant correlations among CPUE for juvenile salmon, three of which were between hatchery and wild fish, which suggests potential hatchery/wild fish interactions inshore. The strongest correlation was between hatchery and wild coho in September-October. Evaluating hatchery/wild fish interactions should be a significant component of any subsequent analyses.

It is important to consider sampling timing in the context of migration timing. As for most studies, sampling for this study focused on chinook and coho. Therefore, fishing occurred later in the summer, after most sockeye, pink, and chum juveniles have left the Strait (Healey 1978). The time trends in inshore CPUE for chinook and coho reflect their tendency to reside longer in the Strait than other salmonids, a conclusion reported in Healey (1978) based on results for fish purse-seined further offshore. Trends in inshore (this study) and nearshore (Healey 1978) CPUE for chum reflect their relatively rapid movement out of the Strait of Georgia. We caught few pink salmon (93 in 1972 and 1 in 1973) or sockeye (*O. nerka*; 18 in 1972 and 2 in 1973) during the inshore study. This likely reflects their rapid movement out of the Strait and possibly their movement from shore over time. Groot *et al.* (1985)'s results suggest that sockeye juveniles migrate into the Strait in April and May, disperse northward along the mainland coast and westward to the Gulf Islands, and leave the Strait of Georgia by late June – early July.

In summary, we found significant effects of time and location on the distribution of wild and hatchery juvenile chinook and coho, juvenile chum, and young-of-the-year herring in the Strait of Georgia. Results of preliminary analyses suggest that effects of hatchery smolt releases, young-of-the-year herring abundance, and harbour seal abundance may be population-specific. Understanding whether or not there are inter- and intra-specific interactions is important for management of the wild and enhanced populations that reside in the Strait of Georgia. We suggest that research to investigate the biological basis of production variability of coho and chinook stocks be conducted at the population level. These studies should include evaluating the possible effects of stock and hatchery production variability, along with assessing the effects of co-occurring species such as Pacific herring and harbour seals. An important task for a comprehensive analysis is to include evaluating the effect that varying food availability in the ocean has on fish productivity. Results of recent work (see Tanasichuk 2002) suggest that understanding how marine prey availability affects fish production would require an experimental approach coupled with long-term monitoring.

Acknowledgments

We thank Mike Bradford and Mary Theiss for their insightful comments on an earlier draft of the manuscript. We also thank Dennis Chalmers and Don Lawseth for their efforts in the field, and Doug Hay and Jake Schweigert for giving us access to the herring data. Mary Thiess and Angus Argyle provided valuable statistical advice. Bryan Rusch and Kristen Daniel prepared the map.

REFERENCES

Anderson, A. D. 1977. Coho and chinook escapements to Areas 12-20 and 28 and 29. Department of the Environment, Fisheries and Marine Service. Memorandum to File 5 900-121-50-1, 3, 5, 11. November 18, 1977. 4p.

Argue, A. W. and Marshall, D. E. 1976. Size and age of chinook and coho salmon for subdivisions of the Strait of Georgia troll fishery. Can. Fish. Mar. Ser. Tech. Rep. PAC/T-76-18. 175p.

Argue, A.W., Hillaby, B. and Shepard, C. D. 1986. Distribution, timing, change in size and stomach contents of juvenile chinook and coho salmon caught in Cowichan estuary and bay, 1973, 1975, 1976. Can. Tech. Rep. Fish. Aquat. Sci. 1431: xvii+151 p.

Barraclough, W. E. and Phillips, A. C. 1978. Distribution of juvenile salmon in the southern Strait of Georgia during the period April to July 1966-69. Fish. Mar. Serv. Tech. Rep. 826: iv+ 47 p.

Beamish, R. J., Jordan, F. P., Scarsbrook, J. R. and Page, R. 1976. An initial study of fishes inhabiting the surface waters of the Strait of Georgia. M. V. Caligus, July - August, 1974. Fish. Res. Board Can. Man. Rep. 1377: ii+37 p.

Beamish, R. J., McCaughran, D., King, J. J., Sweeting, R. M., and McFarlane, G. A. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. North Amer. Jour. Fish. Manage. 20:369-375.

Beamish, R. J., McFarlane, G. A., and Schweigert, J. 2001. Is the production of coho salmon in the Strait of Georgia linked to the production of Pacific herring. *In* Herring: Expectations for the new millennium. Edited by F. Funk, J. Blackburn, D. Hay, A. J. Paul, R. Stephenson, R. Toresen, and D. Witherell. University of Alaska Sea Grant, AK-SG-01-04. Fairbanks, Alaska. Pp. 37-50.

Bigg, M. A., Ellis, G. M., Cottrell, P. and Milette, L. 1990. Predation by harbour seals and sea lions on adult salmon in Comox Harbour and Cowichan Bay, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1769: iv+31p.

Boldt, J. L. and Haldorson, L. J. 2004. Size and condition of wild and hatchery pink salmon juveniles in Prince William Sound, Alaska. Trans. Amer. Fish. Soc. 133:173-184.

Brodeur, R. D., Emmett, R. L., Fisher, J. P., Casillas, E., Teel, D. J. and Miller, T. W. 2004. Juvenile salmonid distribution, growth, condition, origin and environmental and species associations in the Northern California Current. Fish. Bull. 102:25-46.

Conover, W. J. 1980. Practical nonparametric statistics. John Wiley & Sons. New York. 493p.

Cottrell, P. E. 1995. Diet, activity budgets, and movement patterns of harbour seals (*Phoca vitulina*) in Cowichan Bay and adjacent areas. M.Sc. thesis, University of Victoria, Victoria, British Columbia. 118p.

Dawley, E. M., Sims, C. W., Ledgerwood, R. D., Miller, D. R. and Williams, J. G. 1981. A study to define the migration characteristics of chinook and coho salmon in the Columbia River estuary and associated marine waters. Final Report. Northwest and Alaska Fisheries Center, National Marine Fisheries Service. Seattle, WA. USA. 167p.

Godfrey, H. 1968. Some observations on juvenile marine chum, Chinook and Coho salmon taken in waters adjacent to Georgia Strait in 1965. Fish. Res. Board Can. Man. Rep. 955: xx+ 19p.

Groot, C., Cooke, K., Ellis, G. and Bailey, R. 1985. Data record of juvenile sockeye and other fish species captured by purse seine and trawl in the Strait of Georgia, Johnstone Strait and Queen Charlotte Sound in 1982, 1983, 1984, and 1985. Can. Data Rep. Fish. Aquat. Sci. 561: iii +147p.

Healey, M. C. 1978. The distribution, abundance and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Fish. Mar. Serv. Tech. Rep. 788: xx+49p.

Hilborn, R. and Walters, C. J. 1992. Quantitative fisheries stock assessment: choices, dynamics and uncertainty. Chapman and Hall, New York. 570p.

King, J. R. and Beamish, R. J. 2000. Diet comparisons indicate a competitive interaction between ocean age-0 chum and coho salmon. North Pac. Anad. Fish Comm. Bull. 2:65-74.

Olesiuk, P. F. 1999. An assessment of the status harbour seals (*Phoca vitulina*) in British Columbia. Can. Sci. Advis. Secretariat Res. Doc. 99/33.

Olesiuk, P. F., Bigg, M. A., Ellis, G. M., Crockford, S. J., and Wiggen, R. J. 1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia British Columbia, based on scat analysis. Can. Tech. Rep. Fish. Aquat. Sci. 1730: vii+135pp.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, British Columbia. J. Fish. Res. Board Can. 25:757-794.

Peterman, R. M. 1978. Testing for density-dependent marine survival in Pacific salmonids. J. Fish. Res. Board Can. 35:1434-1450.

Peterman, R. M. 1982. Nonlinear relation between smolts and adults in Babine lake sockeye salmon (*Oncohrynchus nerka*) and implications for other salmon populations. Can. J. Fish. Aquat. Sci. 39:904-913.

Simpson, K., M. Chamberlain, J. Fagan, R. Tanasichuk, and D. Dobson. 2004. Forecast for southern and central British Columbia coho salmon in 2004. Can. Sci. Advis. Secretariat Res. Doc. 2004/135.

Sokal, R. R. and Rohlf, F. J. 1995. Biometry: The principles and practice of statistics in biological research. W. H. Freeman and Co, New York. 887p.

Straty, R. R. 1981. Trans-shelf movements of Pacific salmon, p. 575-595, In: D. W. Hood and J. A Calder eds., The eastern Bering Sea shelf: Oceanography and Resources Vol. 1. NOAA. Office of Marine Pollution Assessment. Washington, DC.

Sweeting, R. M., Beamish, R. J., Noakes, D. J. and Neville, C. M. 2003. Replacement of wild coho salmon by hatchery-reared coho in the Strait of Georgia over the past three decades. Nor. Amer. Jour. Fish. Manage. 23:492-502.

Tanasichuk, R. W. 2002. Implications of interannual variability in euphausiid population biology for fish production along the southwest coast of Vancouver Island: a synthesis. Fish. Oceanogr. 11:18-30.

Tompkins, A., Riddell, B., and Nagtegaal, D. A. 2005. A biologically-based escapement goal for Cowichan River fall Chinook salmon (*Oncorhynchus tshawytscha*). Can. Sci. Advis. Secretariat Res. Doc. 2005/095.

Thompson, M., and Hrabok. C. 2007. Strait of Georgia juvenile herring surveys, 2004. Can. Man. Rep. Fish. Aquat. Sci. 2821:v+31 p.

Wilkinson, L., Blank, G. and Gruber, C. 1996. Desktop data analysis with SYSTAT. Prentice-Hall Inc., Upper Saddle River, NJ. 798p.

Zaporozhets, O. M. and Zaporozhets,G. V. 2004. Interaction between hatchery and wild Pacific salmon in the Far East of Russia: A Review. Rev. Fish. Biol. and Fisher. 14:305-319.

Table 1. Number of purse-seine sets.

Region	Area	Sampling period		
		June	Jul-Aug	Sep-Oct
			1972	
Fraser River	Fraser River estuary	0	0	7
	Burrard Inlet/Howe Sound	0	15	18
Central Strait	Upper West	0	0	0
	Lower West	0	0	0
	Eastern	0	0	0
Gulf Islands	Upper	6	11	6
	Lower	0	0	0
			1973	
Fraser River	Fraser River estuary	0	0	0
	Burrard Inlet/Howe Sound	12	11	15
Central Strait	Upper West	14	13	9
	Lower West	10	10	21
	Eastern	1	2	0
Gulf Islands	Upper	6	15	11
	Lower	12	15	23
			1974	
Fraser River	Fraser River estuary	0	0	0
	Burrard Inlet/Howe Sound	0	0	0
Central Strait	Upper West	0	0	26
	Lower West	0	0	7
	Eastern	0	0	4
Gulf Islands	Upper	0	0	20
	Lower	0	0	6

Table 2. Frequency of no significant effects of area on CPUE, within region.

Species/origin group	No. tests	Frequency
Hatchery coho	6	4
Wild coho	6	5
Hatchery chinook	6	5
Wild chinook	6	6
Chum	9	9
Herring	9	7

Table 3. Median (first row) and range (second row) of CPUE by region and sampling period, 1973. Minimum CPUE in all instances is 0.

	Species x Origin					
	Chinook		Coho		Chum	Herring
Region	Hatchery	Wild	Hatchery	Wild	Wild	Wild
			June			
Fraser River	0	8	1	1	0	275
	18	92	6	10	275	20000
Central Strait	0	0	0	0	31	0
	0	2	22	36	650	15000
Gulf Islands	0	0	0	5	2	760
	0	5	0	18	470	30000
			Jul–Aug			
Fraser River	0	13	0	1	1	350
	11	58	6	5	2	10000
Central Strait	0	0	0	4	3	0
	49	14	40	308	352	12000
Gulf Islands	0	7	0	7	2	300
	0	43	10	155	220	21200
			Sep – Oct			
Fraser River	0	2	0	2	0	100
	14	8	10	17	7	2500
Central Strait	0	0	1	9	0	0
	3	1	39	182	11	3500
Gulf Islands	0	18	0	2	0	375
	10	111	5	45	69	9100

Table 4. Median proportion of hatchery chinook and coho caught, 1973. Values in parentheses are total number of fish caught. b – no hatchery fish caught.

	Sampling period					
	June		Jul-Aug		Sep-Oct	
Region	Chinook	Coho	Chinook	Coho	Chinook	Coho
Fraser River	0 (217)	0.36 (42)	0 (252)	0 (26)	0 (66)	0 (58)
Central Strait	0[b] (6)	0.30 (117)	0.95 (220)	0.14 (485)	0 (8)	0.05 (1198)
Gulf Islands	0[b] (10)	0[b] (82)	0[b] (306)	0 (622)	0 (851)	0 (271)

Table 5. Coded-wire tag returns, 1973. FR – Fraser River estuary; BH – Burrard Inlet/Howe Sound; UW – Upper West Strait; LW – Lower West Strait; ES – Eastern Strait; UG – Upper Gulf Islands; LG – Lower Gulf Islands. Days – minimum to maximum days at large.

Release area		Recapture area						
		FR	BH	UW	ES	LW	UG	LG
					Chinook			
BH	No. CWT	0	10	0	0	0	0	0
	Days	.	51 – 52	.	.	.	.	.
UW	No. CWT	0	0	11	0	24	0	0
	Days	.	.	36 – 39	.	20 – 99	.	.
					Coho			
BH	No. CWT	0	11	2	0	11	4	2
	Days	.	22 – 59	118	.	106 – 116	38 – 101	39
UW	No. CWT	0	0	82	0	26	0	0
	Days	.	.	13 – 167	.	17 – 149	.	.

Table 6. Correlation coefficients for CPUE, 1972-1974. * - p<0.05; ** - p<0.01.

	Spearman's *rho*				
	Chinook		Coho		Chum
Species x Origin	Hatchery	Wild	Hatchery	Wild	
			June		
Hatchery chinook					
Wild chinook	0.36				
Hatchery coho	0.22	0.24			
Wild coho	-0.05	0.32	0.20		
Chum	-0.12	-0.21	-0.20	-0.08	
Herring	0.20	0.26	-0.08	0.06	-0.38*
			Jul-Aug		
Hatchery chinook					
Wild chinook	-0.12				
Hatchery coho	0.08	-0.30			
Wild coho	-0.03	-0.16	0.37**		
Chum	0.08	-0.32*	0.10	0.42**	
Herring	-0.25	0.44**	-0.3	0.03	-0.19
			Sep-Oct		
Hatchery chinook					
Wild chinook	0.15				
Hatchery coho	-0.13	-0.35**			
Wild coho	0.00	-0.07	0.66**		
Chum	0.13	-0.06	0.21	0.28**	
Herring	0.25*	0.55**	-0.39**	-0.29**	-0.06

Table 7. Statistics for regression analyses. β' – standardised regression coefficients. p_{adj} - Bonferroni adjusted probability. a - CWT marine survival. b – total return.

Parameter	Estimate	Std. error	*p*	β'
Quinsam Hatchery coho[a] Adj. R^2=0.83, n=12, p=0.0001, p_{adj}=0.05/28=0.0018)				
Intercept	0.17	0.019	<0.0001	0.00
Herring CPUE	-1.44	0.684	0.0640	-0.26
Seal abundance	-4.00E-06	5.400E-07	<0.0001	-0.94
Black Creek wild coho[a] (Adj. R^2=0.39 n=12, p=0.0446, p_{adj}=0.05/15=0.003)				
Intercept	0.30	0.089	0.0084	0.00
Herring CPUE	-6.01	3.191	0.0926	-0.45
Seal abundance	-6.60E-06	2.535E-006	0.0280	-0.63
Big Qualicum Hatchery coho[a] (Adj. R^2=0.80, n=12, p=0.0002, p_{adj}=0.05/28=0.0018)				
Intercept	67.45	12.183	0.0004	0.00
Ln herring CPUE	-0.25	0.066	0.0045	-0.51
Ln seal abundance	-7.01	1.170	0.0002	-0.81
Salmon River wild coho[a] (Adj. R^2=0.69, n=12, p=0.0021, p_{adj}=0.05/10=0.005)				
Intercept	0.25	0.043	0.0002	0.00
Herring CPUE	-5.33	1.513	0.0065	-0.60
Seal abundance	-5.19E-06	1.202E-06	0.0019	-0.73
Chilliwack River Hatchery coho[a] (Adj. R^2=0.89, n=21, p<0.0001, p_{adj}=0.05/28=0.0018)				
Intercept	0.22	0.014	<0.0001	0.00
Coho smolt release	2.41E-08	9.240E-09	0.0179	0.26
Seal abundance	-6.60E-06	5.950E-07	<0.0001	-1.10
Inch Creek Hatchery coho[a] (Adj. R^2=0.51, n=18, p=0.0004, p_{adj}=0.05/15=0.0033)				
Intercept	0.20	0.033	<0.0001	.
Seal abundance	-4.50E-06	1.030E-06	<0.0001	.
North Thompson wild coho[b] (Adj. R^2=0.47, n=12, p=0.0002, p_{adj}=0.05/10=0.005)				
Intercept	225362	32783.7	<0.0001	.
Seal abundance	-5.26	1.156	0.0002	.
South Thompson wild coho[b] (Adj. R^2=0.32, n=26, p=0.0014, p_{adj}=0.05/10=0.005)				
Intercept	2.95	1.882	0.1302	.
Ln parents	0.77	0.213	0.0014	.
Lower Thompson wild coho[b] (Adj. R^2=0.40, n=12, p=0.0401, p_{adj}=0.05/10=0.005)				
Intercept	58.05	19.866	0.0170	0.00
Ln herring abundance	-0.21	0.108	0.0815	-0.46
Ln seal abundance	-4.83	1.907	0.0320	-0.59
Cowichan River wild fall chinook[a] (Adj. R^2=0.39, n=13, p=0.0130, p_{adj}=0.05/28=0.0018)				
Intercept	0.87	0.022	0.0023	.
Seal abundance	-2.00E-06	6.800E-07	0.0027	.

Table 8. Wild spawning escapement and hatchery juvenile production of chinook and coho, Strait of Georgia for the 1973 out-migration year. Spawning escapements are for brood year +1 for chinook because Argue and Marshall (1976) reported that stream-type chinook, fish which rear in freshwater for at least one year, made up less than 6% of the Strait of Georgia troll catch. So, most chinook would be ocean-type which are fish which rear in freshwater for several months only. Spawning escapements for coho are for brood year + 2 because coho rear in freshwater for one year. Wild escapement data are from Anderson (1977).

	Origin	
Species	Hatchery	Wild
	Fraser River estuary	
Chinook	0	44929
Coho	0	98184
	Burrard Inlet/Howe Sound	
Chinook	298967	9850
Coho	284607	49350
	Upper West Central Strait	
Chinook	626162	1860
Coho	244526	52050
	Eastern Central Strait	
Chinook	0	11700
Coho	0	44300
	Lower West Central Strait	
Chinook	0	1950
Coho	0	4340
	Upper Gulf Islands	
Chinook	0	60
Coho	0	4300
	Lower Gulf Islands	
Chinook	0	8775
Coho	0	78500

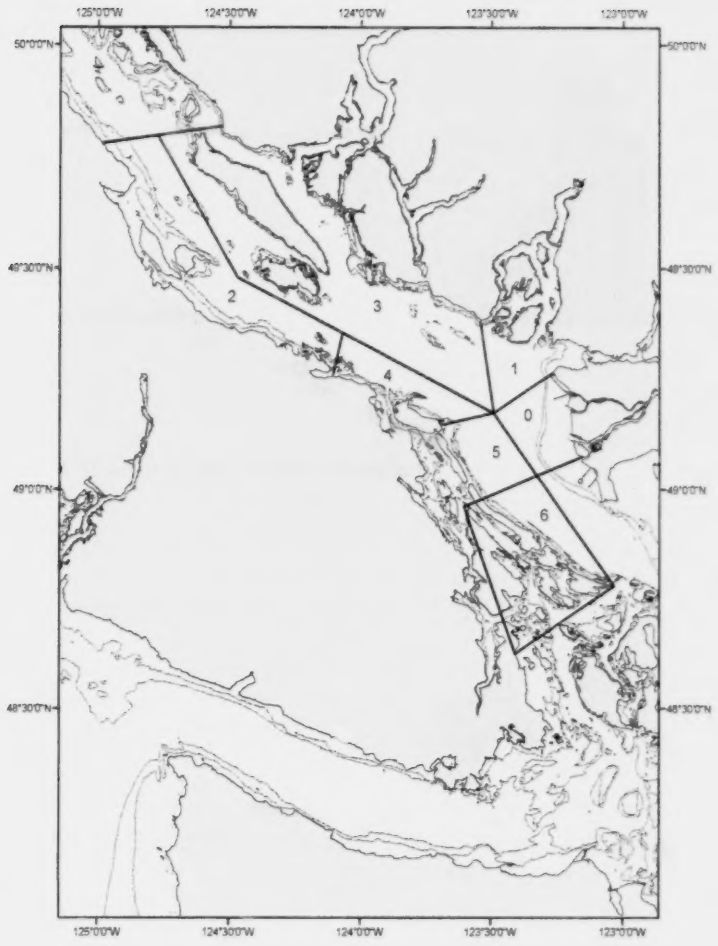

Figure 1. Study area. Numbers identify areas. The Fraser River region consists of Areas 0 (Fraser River estuary) and 1 (Burrard Inlet/Howe Sound). The Central Strait region includes Areas 2 (Upper West Strait), 3 (Eastern Strait), and 4 (Lower West Strait). The Gulf Islands region consists of Areas 5 (Upper Gulf Islands) and 6 (Lower Gulf Islands). Lines seaward of the coast are the 50 and 100 m depth contours respectively. The 50 and 100 m contours are an average of 0.9 and 2.7 km respectively away from shore. The top of the figure is North.

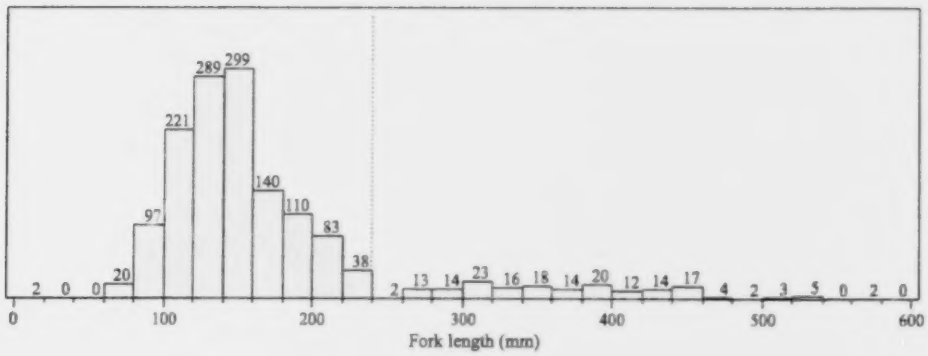

Figure 2. Length-frequency histogram for chinook salmon seined over 1972-74. Values are counts. Dotted line is at 240 mm.

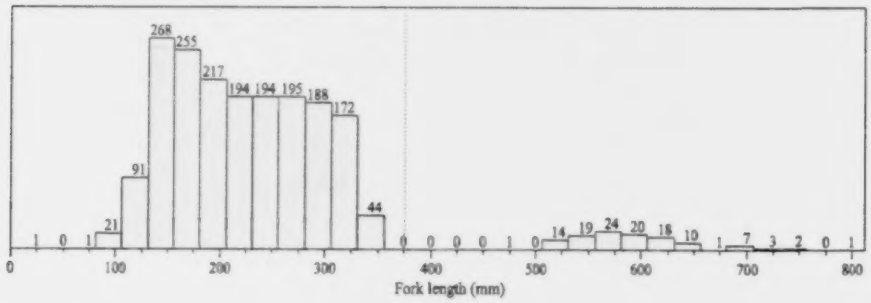

Figure 3. Length-frequency histogram for coho salmon. Dotted line is at 370 mm.

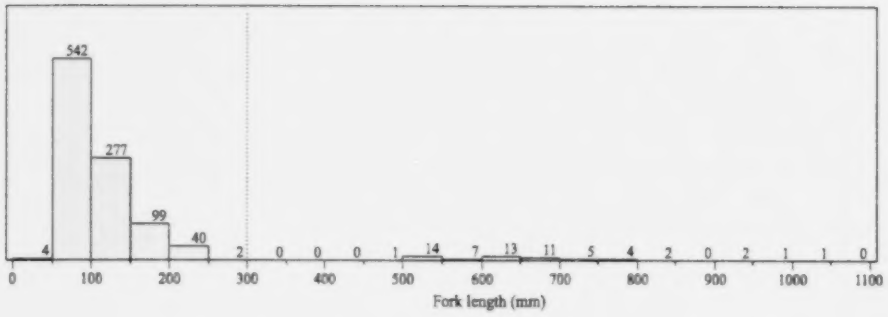

Figure 4. Length-frequency histogram for chum salmon. Dotted line is at 300 mm.

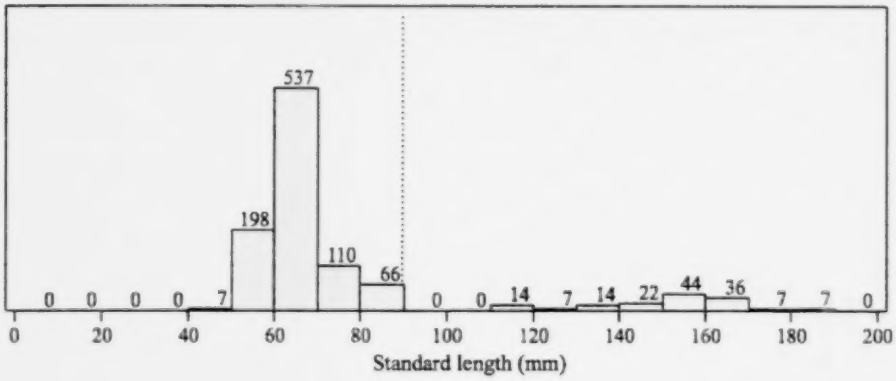

Figure 5. Length-frequency histogram for herring. Dotted line is at 90 mm.

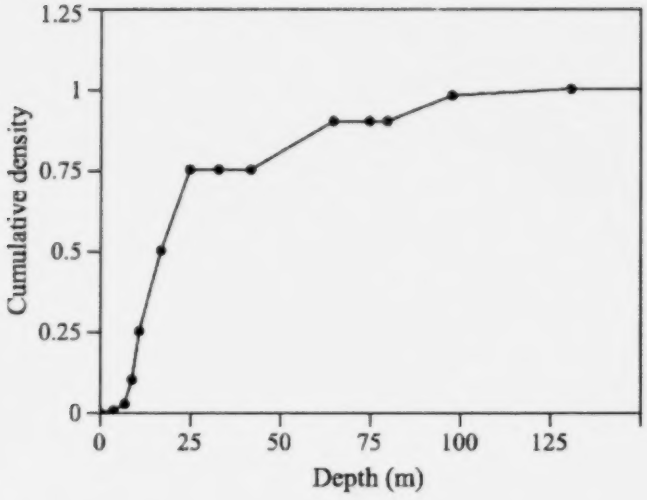

Figure 6. Cumulative density plot for bottom depth at purse seine set locations.

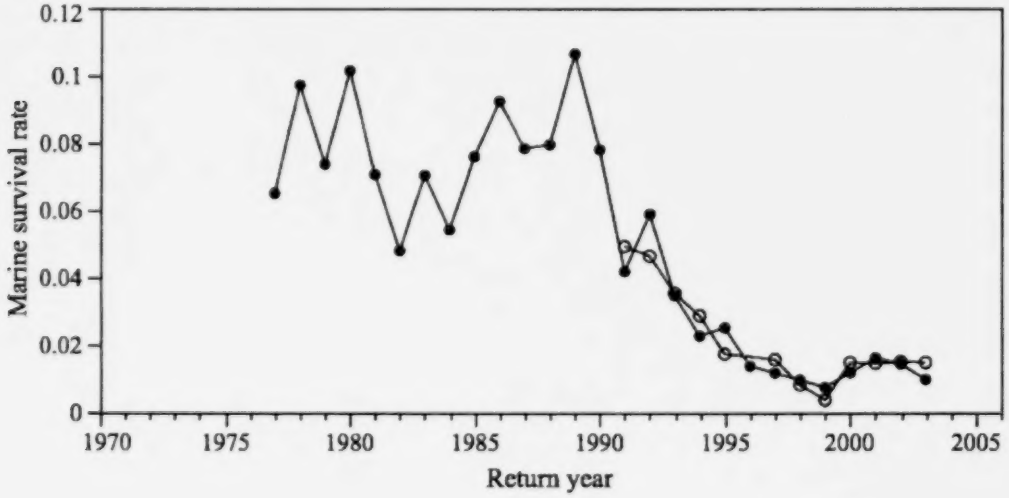

Figure 7. Observed (closed circle) and predicted (open circle) marine survival rate for Quinsam Hatchery coho. Independent variables are herring CPUE and seal abundance.

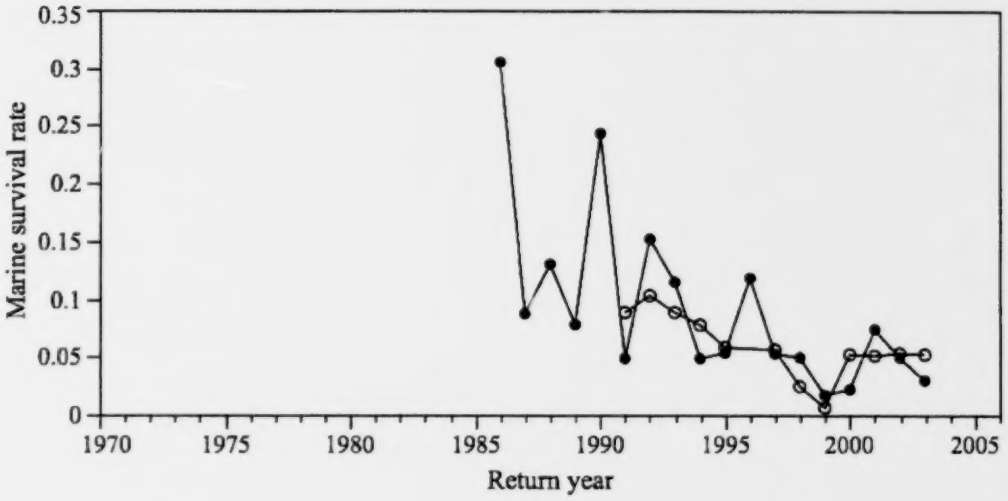

Figure 8. Observed and predicted marine survival rate for Black Creek wild coho. Independent variables are herring CPUE and seal abundance.

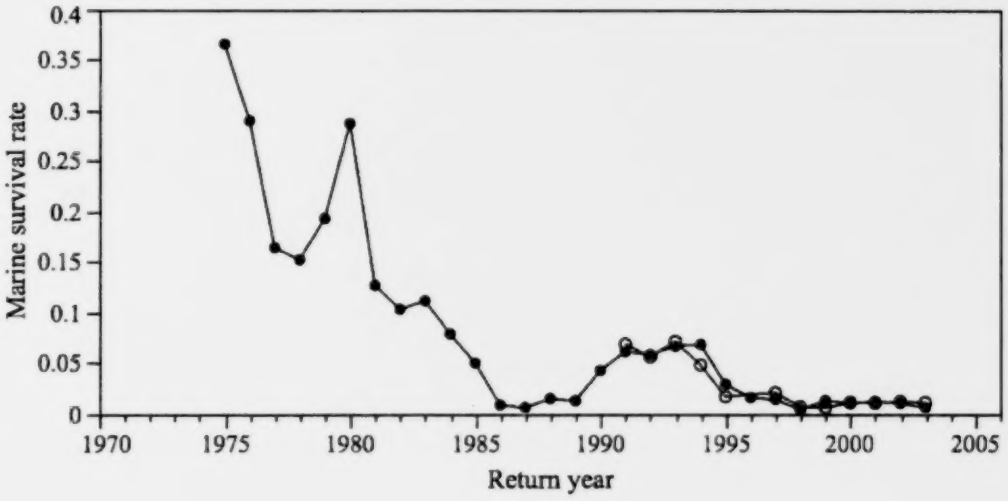

Figure 9. Observed and predicted marine survival rate for Big Qualicum Hatchery coho. Independent variables are ln herring CPUE and ln seal abundance. Plotted survival rate is back-transformed natural logarithm (ln) marine survival rate.

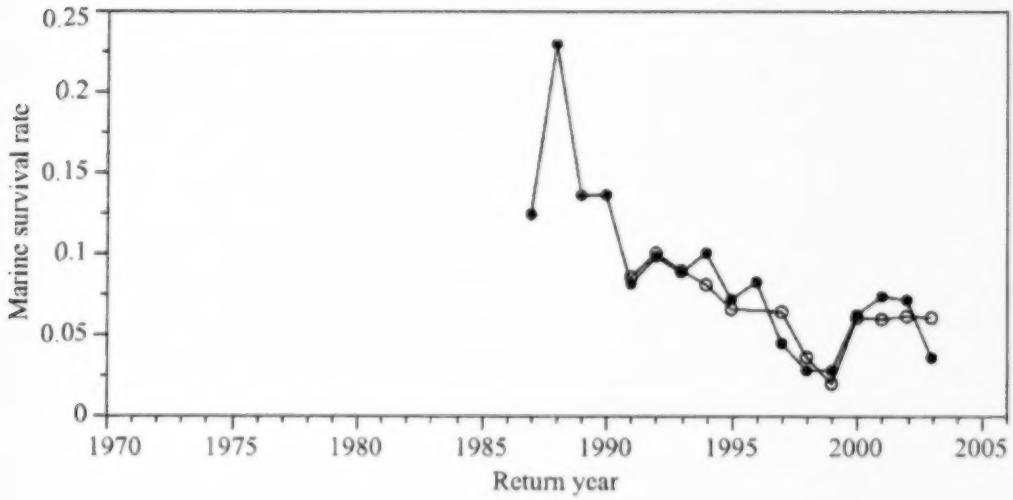

Figure 10. Observed and predicted marine survival rate for Salmon River wild coho. Independent variables are herring CPUE and seal abundance.

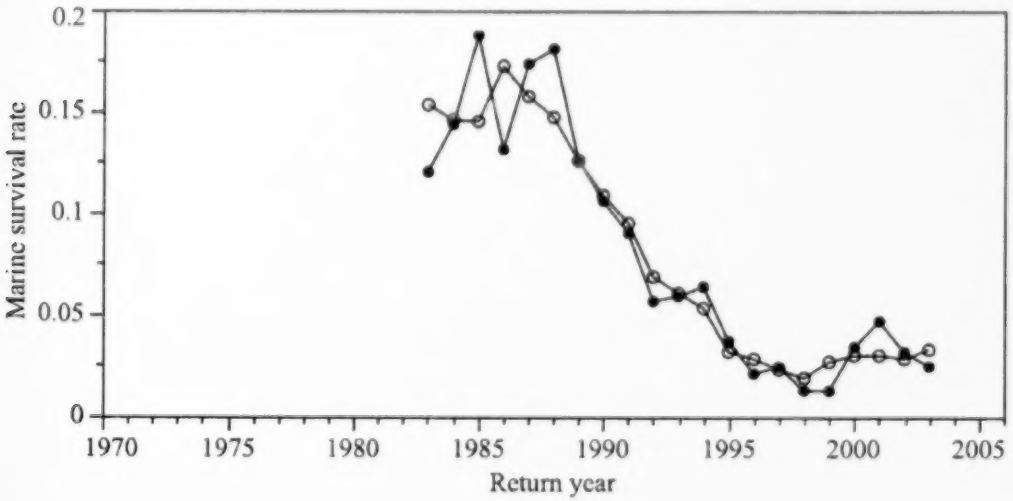

Figure 11. Observed and predicted marine survival rate for Chilliwack River Hatchery coho. Independent variables are total coho smolt release and seal abundance.

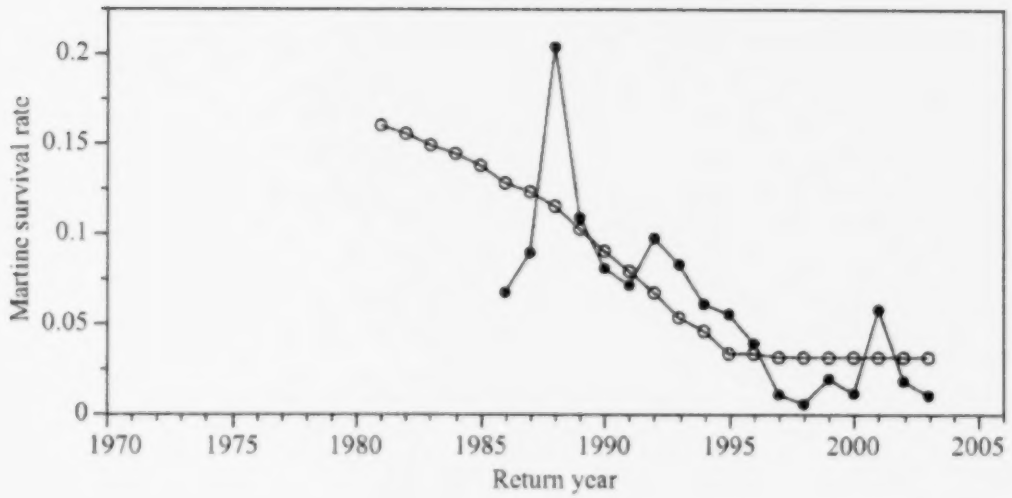

Figure 12. Observed and predicted marine survival rate for Inch Creek Hatchery coho. Independent variable is seal abundance.

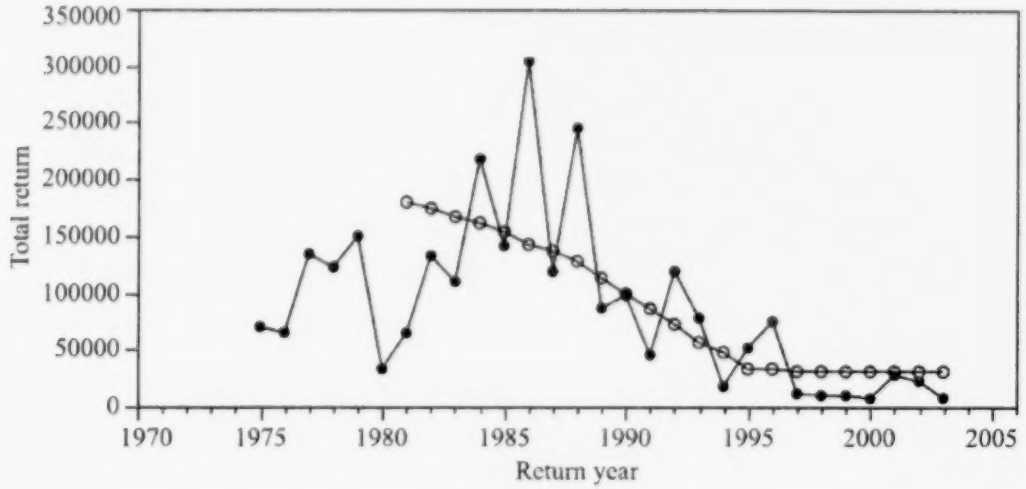

Figure 13. Observed and predicted total return for North Thompson River coho. Independent variable is seal abundance.

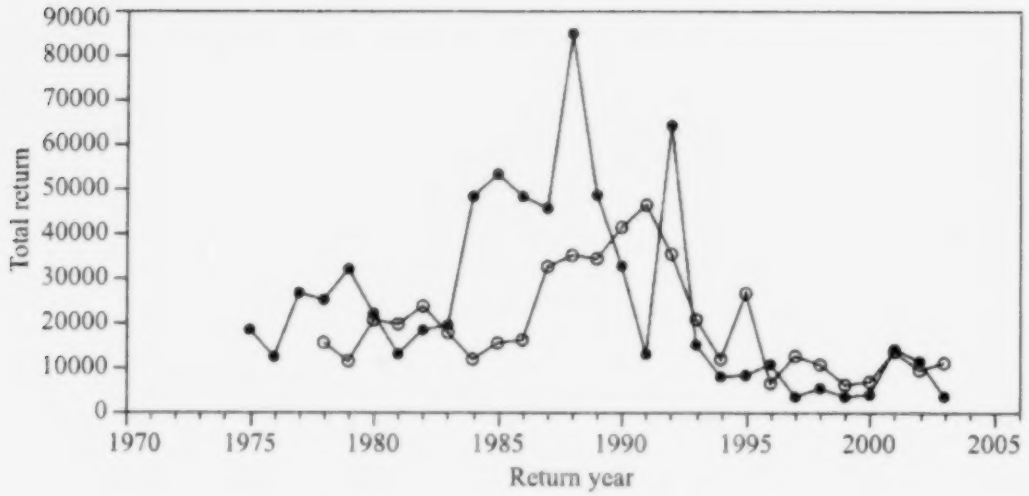

Figure 14. Observed and predicted total return for South Thompson River coho. Independent variable is ln parental abundance. Plotted return is back-transformed ln total return.

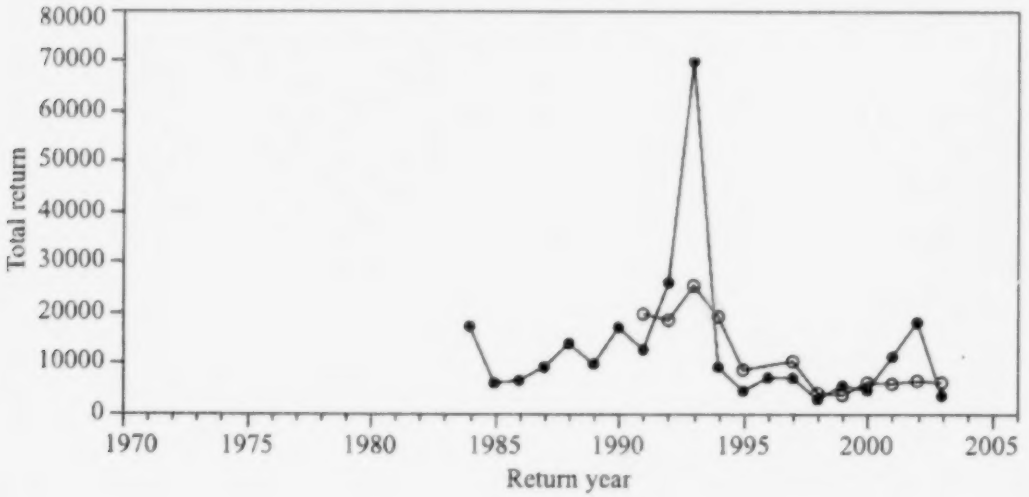

Figure 15. Observed and predicted total return for Lower Thompson River coho. Independent variables are ln herring CPUE and ln seal abundance. Plotted return is back-transformed ln total return.

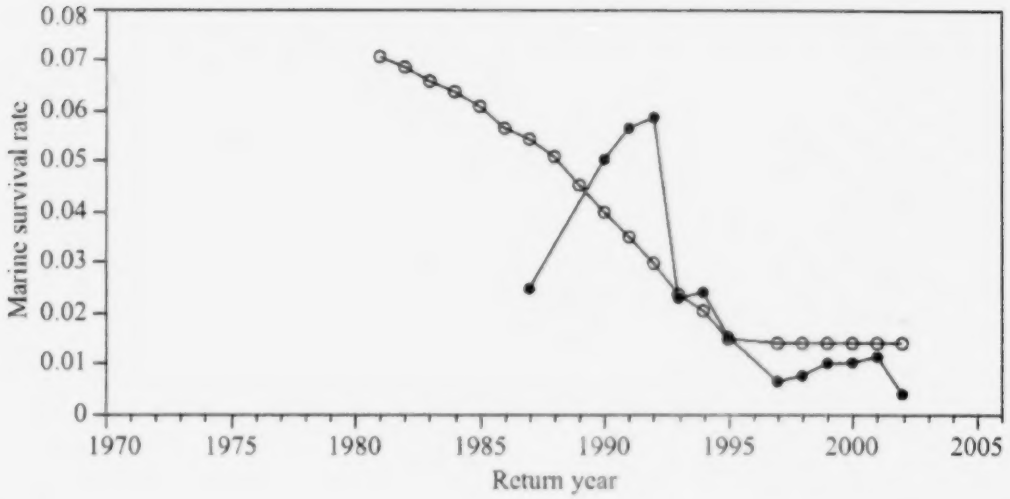

Figure 16. Observed and predicted marine survival rate for Cowichan River fall chinook. Independent variable is seal abundance.

This page is blank

Appendix Table 1. Population-specific coho smolt abundance, total return, parental abundance, and total coho and chinook smolt releases by smolt and return year.

		Quinsam River Hatchery coho				Black Creek wild coho			
Smolt	Return	CWT		Total release		CWT		Total	
year	year	Smolts	Return	Coho	Chinook	Smolts	Return	Smolts	Parents
1974	1975	.	.	.	.	.	.	.	.
1975	1976	.	.	.	.	.	.	.	.
1976	1977	57502	3739	1439951	424567	.	.	.	.
1977	1978	73442	7134	661667	376480	.	.	.	.
1978	1979	72104	5312	537382	776387	.	.	.	.
1979	1980	117667	11933	1331237	849226	.	.	.	.
1980	1981	57158	4035	1356315	1081433	.	.	.	.
1981	1982	88610	4255	955935	1136778	.	.	.	.
1982	1983	57385	4038	1275830	728221	.	.	.	.
1983	1984	102021	5531	948180	978040	.	.	.	.
1984	1985	147404	11188	1174047	1329135	.	.	.	.
1985	1986	100360	9266	852840	3060595	24134	7355	50208	.
1986	1987	57573	4514	1201640	2992602	31648	2757	38212	.
1987	1988	42176	3352	1287066	3309673	35640	4629	60909	.
1988	1989	44457	4729	552943	3142791	74997	5836	75210	824
1989	1990	39362	3068	1057725	3088401	29203	7094	29726	559
1990	1991	39466	1650	586059	3007294	118382	5749	118748	1542
1991	1992	39400	2317	588308	3251547	52351	7941	53536	2603
1992	1993	39411	1365	1220201	3255752	49873	5710	50131	1080
1993	1994	42470	965	1224754	2930097	54898	2665	64968	3069
1994	1995	36277	912	1128936	1753678	76003	4064	77947	1522
1995	1996	38947	536	1193987	1830676	18152	2141	18216	.
1996	1997	59418	697	1215267	1469921	13736	722	13865	685
1997	1998	62702	603	1249119	1960330	69996	3449	76269	1484
1998	1999	39813	297	1466392	1725418	24582	419	24714	182
1999	2000	39322	464	1545322	2215622	26247	572	26294	292
2000	2001	42352	683	1483497	2194648	151129	11123	153986	3085
2001	2002	42996	617	1289984	1711295	42419	2097	42628	406
2002	2003	42665	418	1454810	2157492	88421	2611	89257	555

Appendix Table 1 cont.

		Big Qualicum River Hatchery coho				Salmon River Wild coho		
Smolt	Return	CWT		Total release		CWT		
year	year	Smolts	Return	Coho	Chinook	Smolts	Return	Parents
1974	1975	100933	36951	182055	397050	.	.	.
1975	1976	57425	16645	377765	230571	.	.	.
1976	1977	75512	12416	672372	875852	.	.	.
1977	1978	90520	13795	833081	814310	.	.	.
1978	1979	38748	7485	852130	2843510	.	.	.
1979	1980	50224	14423	677815	2554090	.	.	.
1980	1981	45328	5754	987395	3206087	.	.	.
1981	1982	55435	5728	1197409	4335402	.	.	.
1982	1983	51984	5802	1182746	3466788	.	.	.
1983	1984	49274	3893	1169263	2799374	.	.	.
1984	1985	42453	2130	1254712	3176976	.	.	.
1985	1986	21868	189	3522034	3780332	.	.	.
1986	1987	87365	542	2658239	4727224	10059	1245	.
1987	1988	74194	1113	1472413	7021836	20022	4593	.
1988	1989	27462	355	679080	6134313	24634	3342	.
1989	1990	42412	1818	957024	5440607	26911	3656	406
1990	1991	44813	2757	1134810	5701175	20390	1654	1316
1991	1992	36474	2135	1062989	6115264	29435	2881	921
1992	1993	37362	2492	1142312	4854024	28141	2476	970
1993	1994	38235	2620	1168887	4204039	15611	1562	448
1994	1995	37957	1115	1158714	3627454	35256	2517	769
1995	1996	38917	622	1508383	4036768	30052	2467	.
1996	1997	37616	536	1738986	4565442	24719	1101	563
1997	1998	38827	167	1278697	4092348	5872	163	1318
1998	1999	40331	527	1322872	3555166	38369	1069	1065
1999	2000	37806	395	887883	3808648	28883	1793	972
2000	2001	40836	502	1371303	3762539	25163	1844	152
2001	2002	40596	426	1362178	3477099	27269	1941	973
2002	2003	41543	266	1232961	4318854	21602	771	1727

Appendix Table 1 cont.

Smolt year	Return year	Inch Creek Hatchery coho CWT Smolts	CWT Return	Total Release Coho	Chilliwack River Hatchery coho CWT Smolts	CWT Return	Total release Coho	Chinook
1974	1975	.	.	.	.	.	.	.
1975	1976	.	.	.	.	.	.	.
1976	1977	.	.	.	.	.	.	.
1977	1978	.	.	.	.	.	.	.
1978	1979	.	.	.	.	.	.	.
1979	1980	.	.	.	.	.	.	.
1980	1981	.	.	.	.	.	.	.
1981	1982	.	.	.	.	.	.	.
1982	1983	.	.	.	54665	6579	59358	419207
1983	1984	.	.	.	28502	4099	31516	1131701
1984	1985	.	.	.	100841	18943	393925	1027914
1985	1986	38711	2591	80268	27851	3661	2119869	978395
1986	1987	38774	3449	99414	129770	22538	1788359	657652
1987	1988	19723	4014	106533	59935	10855	1835406	578637
1988	1989	19504	2116	194814	68658	8663	1706288	1519756
1989	1990	27458	2206	82129	39250	4161	1728963	1277929
1990	1991	38019	2700	190725	39801	3597	1828481	722326
1991	1992	29367	2850	153120	39500	2243	1439714	1385811
1992	1993	31629	2611	183104	39797	2357	1942508	1525715
1993	1994	21172	1280	229647	39673	2533	2083037	2302475
1994	1995	20303	1116	242949	39654	1480	1939584	2296286
1995	1996	21540	837	257049	74456	1583	1795181	2066060
1996	1997	21174	223	231092	36256	889	1702085	1255769
1997	1998	38707	202	477089	74456	967	1525935	2310465
1998	1999	41918	804	209702	37282	478	1857069	2330781
1999	2000	40206	450	363436	82059	2813	1988176	2333686
2000	2001	40201	2315	495959	36976	1737	1988529	1632985
2001	2002	39911	721	189092	42795	1362	1919489	1057671
2002	2003	39998	402	454642	38726	959	2108776	1590378

Appendix Table 1 cont.

Smolt	Return	South Thompson		North Thompson		Lower Thompson	
year	year	Parents	Return	Parents	Return	Parents	Return
1974	1975	.	18354	.	69754	.	.
1975	1976	.	12268	.	64713	.	.
1976	1977	.	26572	.	133975	.	.
1977	1978	5864	25028	22286	122364	.	.
1978	1979	3920	31918	20675	149670	.	.
1979	1980	8490	21989	42804	32996	.	.
1980	1981	7996	12895	39095	64524	.	.
1981	1982	10198	18308	47819	132382	.	.
1982	1983	7025	19392	10542	109816	.	.
1983	1984	4120	48183	20615	217692	.	17205
1984	1985	5849	53204	42295	141349	.	5973
1985	1986	6196	48186	35086	304113	.	6511
1986	1987	15394	45564	69552	118594	5155	9153
1987	1988	16998	84802	45160	245150	1913	13843
1988	1989	16521	48496	104267	86455	2211	9763
1989	1990	21087	32677	54884	97542	4208	17021
1990	1991	24426	12896	70612	45217	4013	12619
1991	1992	17208	64125	30677	118917	3423	25905
1992	1993	8609	15045	25697	77667	4421	69916
1993	1994	4160	7915	14585	17702	3794	9217
1994	1995	11886	8261	22042	51272	4905	4509
1995	1996	1873	10667	9669	74645	8416	7109
1996	1997	4485	3418	10031	11295	5252	7037
1997	1998	3622	5321	22477	9810	1984	2828
1998	1999	1760	3379	12319	9801	1209	5502
1999	2000	2034	3919	6722	7282	4217	4616
2000	2001	4946	14094	9125	27710	2628	11249
2001	2002	3074	11372	8916	22480	5007	18079
2002	2003	3785	3531	7032	7481	4459	3597

Appendix Table 2. Brood year-specific wild and hatchery smolt production, parental abundance and total return for Cowichan River fall chinook salmon.

Brood year	Smolt year	Smolt production		Wild	
		Wild	Hatchery	Parents	Return
1981	1982	.	.	5500	42129
1982	1983	.	.	4500	27326
1983	1984	.	.	4500	15622
1984	1985	.	.	5000	26705
1985	1986	1001085	63886	3500	24727
1986	1987	.	.	1832	55583
1987	1988	.	.	1937	40435
1988	1989	1743880	855282	6200	87700
1989	1990	608545	736939	5000	34377
1990	1991	482152	655901	5300	28244
1991	1992	763686	3079120	6000	17481
1992	1993	1238899	2975343	8500	29758
1993	1994	1610273	2931614	5058	24621
1994	1995	.	.	5050	15288
1995	1996	1181849	2588958	14300	7599
1996	1997	1425872	2878343	12980	10808
1997	1998	981079	270494	9845	9850
1998	1999	422825	2543136	4371	4283
1999	2000	271264	2582056	4500	3068
2000	2001	3438325	2582057	5109	13547

Appendix Table 3. Smolt year-specific young-of-the-year Pacific herring (YOY) CPUE (no. fish • m^{-3}) and harbour seal abundances in the Strait of Georgia.

Smolt year	Median YOY CPUE	Harbour seal abundance
1980	.	8690
1981	.	9711
1982	.	11114
1983	.	12145
1984	.	13595
1985	.	15751
1986	.	16826
1987	.	18557
1988	.	21354
1989	.	24045
1990	6.28E-03	26479
1991	9.89E-04	29079
1992	2.26E-05	32148
1993	2.71E-05	33779
1994	1.90E-04	36535
1995	.	36535
1996	6.32E-05	36973
1997	5.32E-03	36973
1998	8.36E-03	36973
1999	7.32E-04	36973
2000	9.17E-04	36973
2001	5.65E-04	36973
2002	7.32E-04	36973